USING THE VECTOR VORTEX CORONAGRAPH IN THE EXAO REGIME AT PALOMAR: LESSONS LEARNED

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5+ years effort:
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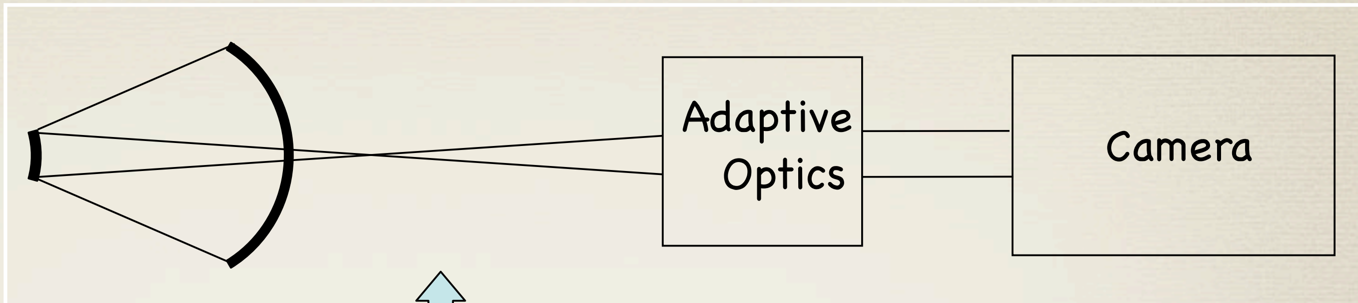
Recipe for high contrast imaging from the ground

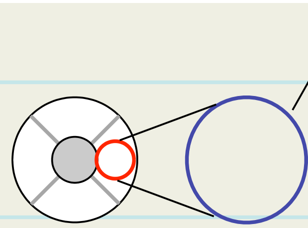
* High Strehl Ratio => Extreme AO

Extreme AO

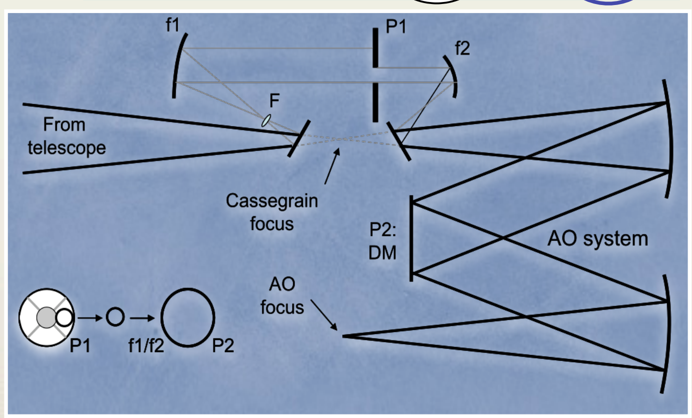
Existing Telescope Optics:

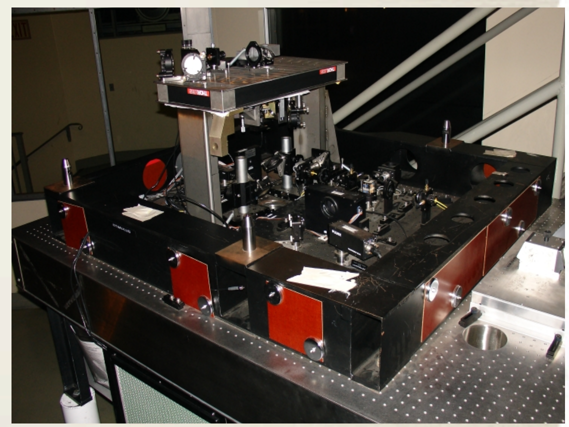


Subaperture reimager

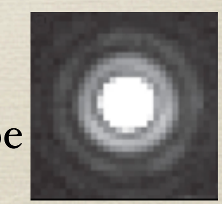


- Keep pupil location at DM
- Magnify pupil (by f1/f2)
- Center sub-pupil on DM
- Maintain F# to AO system
⇒ post-AO optics unchanged





Result: >90% SR, best image quality ever on a ground-based telescope



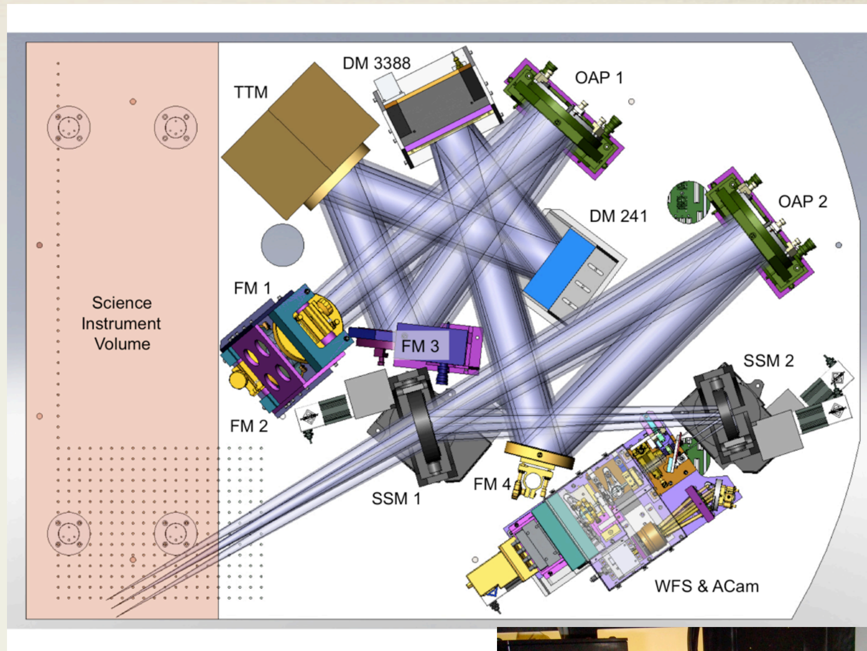
Recipe for high contrast imaging from the ground

* High Strehl Ratio => Extreme AO ✓
* Pointing stabilization => new SSM

New SSM

SSM are responsible for pointing accuracy and stability (≠ tip-tilt), which is the most fundamental requirement in high contrast imaging:

- Old SSM had 20 mas accuracy, and intrinsic drifts.
- New SSM have ***mas-level*** pointing accuracy and very little drift.
- Are now commanded with feedback from the science image.



- ***Dynamic tip-tilt is fundamentally limited by the tip-tilt mirror inertia, but can be specifically addressed by fine tuning the tip-tilt loop gain in real time.***

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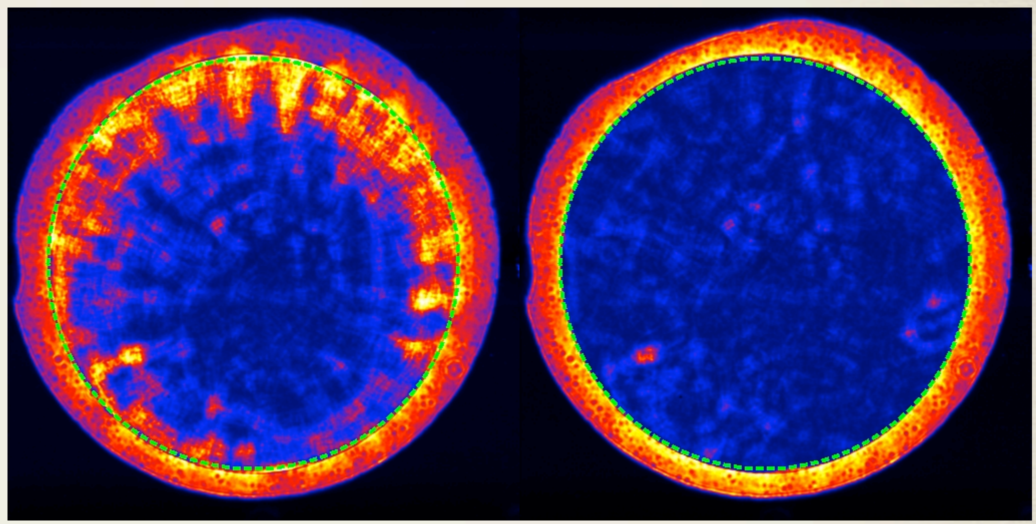
- Low-order aberration (focus) => pupil imaging

Fine focus tuning

Pupil imaging capability



No control loop correction, one time fine tuning.
Then relying on AO to keep it steady

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- High Strehl Ratio => Extreme AO ✓
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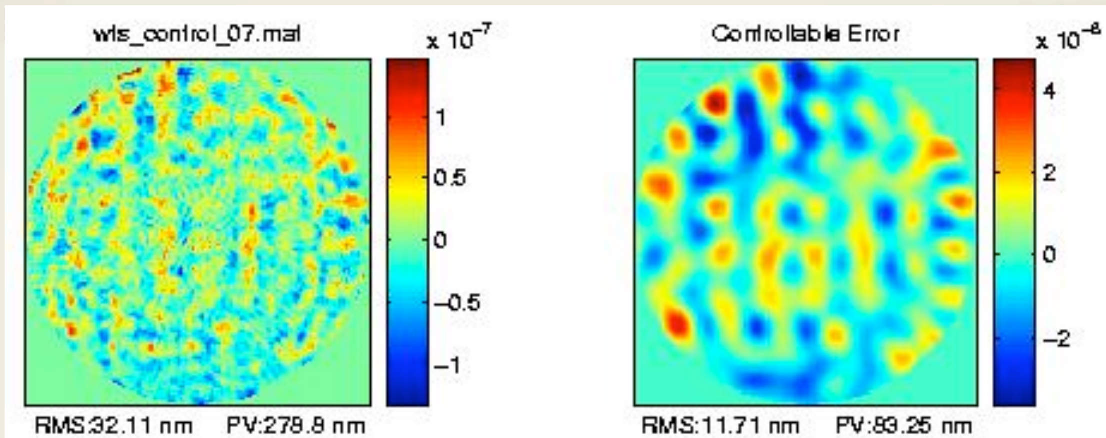
- Low-order aberration (focus) => pupil imaging ✓
- Quasi-static aberrations measurement and correction => Modified Gerchberg Saxton phase-retrieval

Autonomous Phase Retrieval Calibration

* Modified Gercherg-Saxton (MGS):
  * takes out-of-focus pairs of images with science camera (sense aberrations down to the final focal plane).
  * Off-line process (internal white light of the AO bench).
  * Performed for each new target.

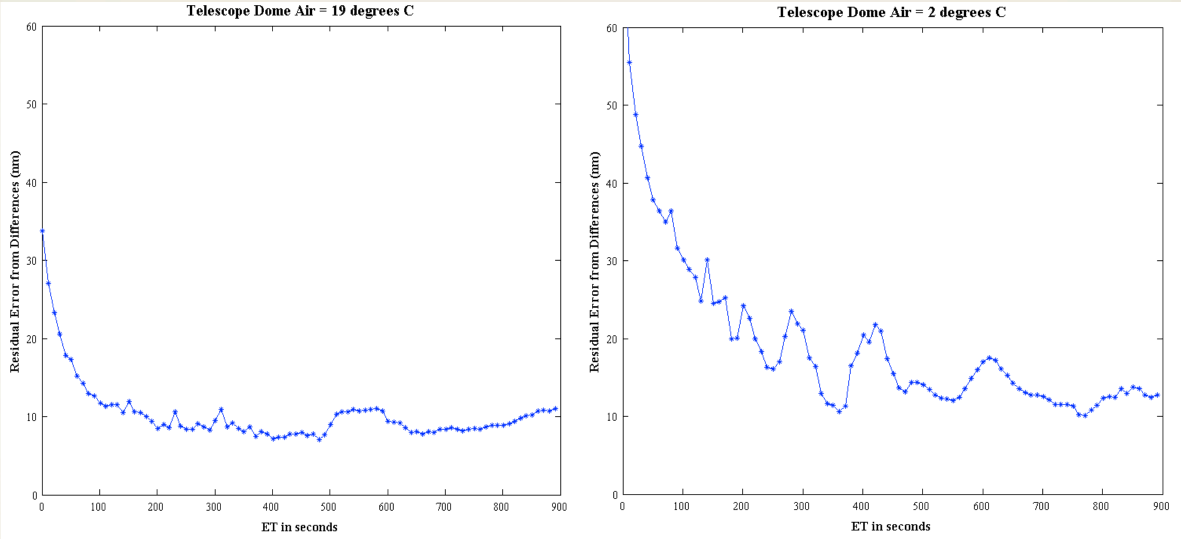
APRC



Best result: 11.71 nm rms within the DM bandwidth

APRC limitation

* Turbulence on the AO bench itself !



* APRC only senses and correct phase aberrations...

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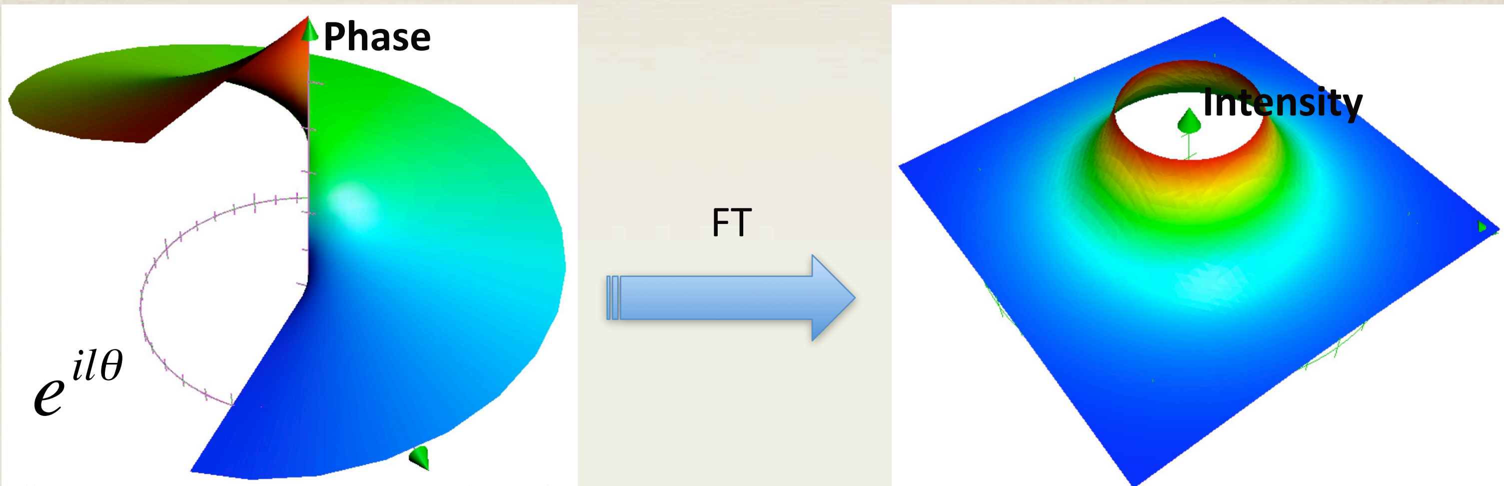
- Small Inner Working Angle Coronagraph => Vector Vortex Coronagraph

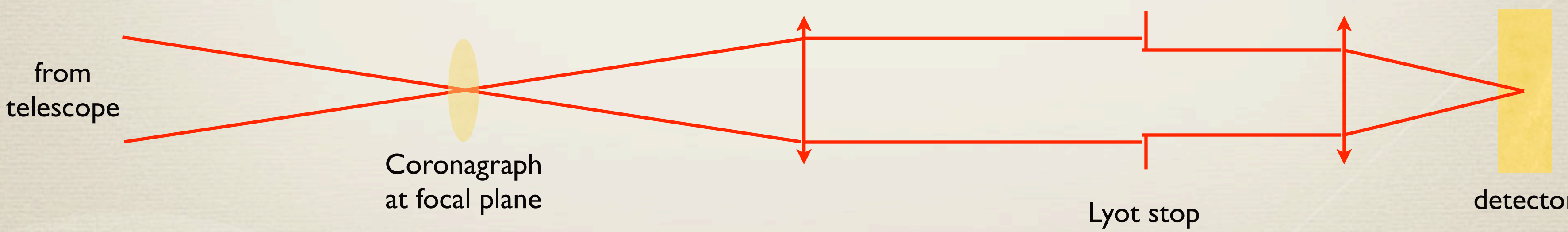
Vector Vortex Coronagraph



"Phase screw dislocation" at focal plane

l = topological charge

Clears out the relayed pupil



Selling points: small IWA (~1 λ/d), efficiency, clear 360° off-axis discovery space, rapid implementation

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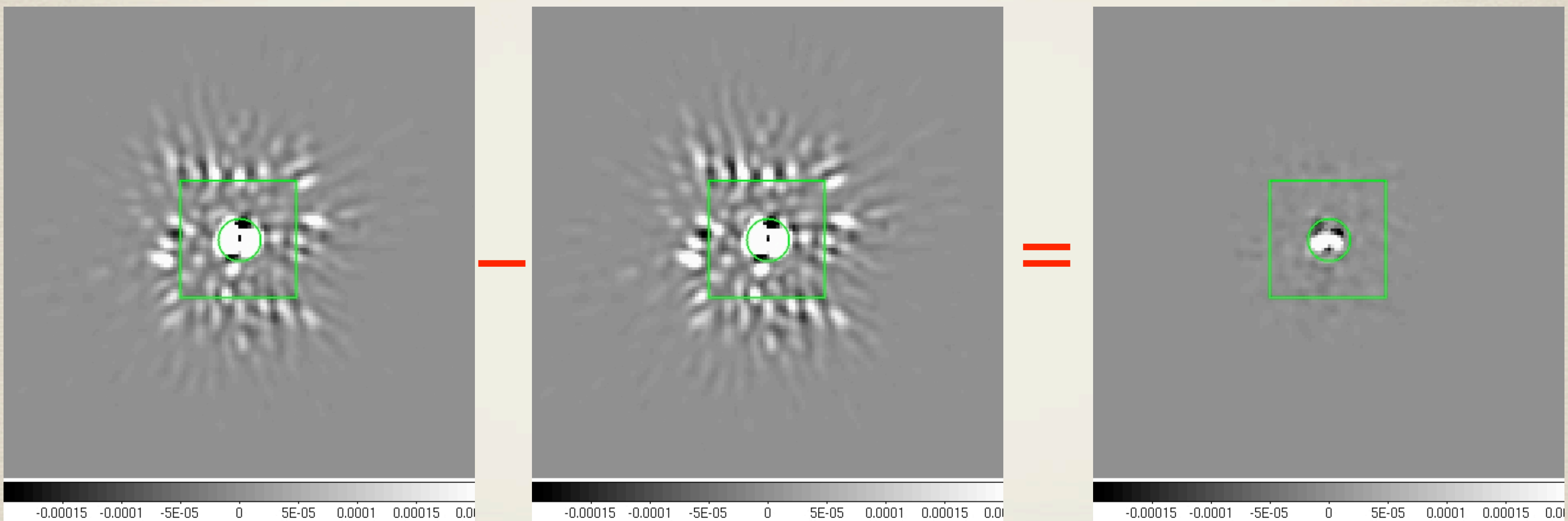
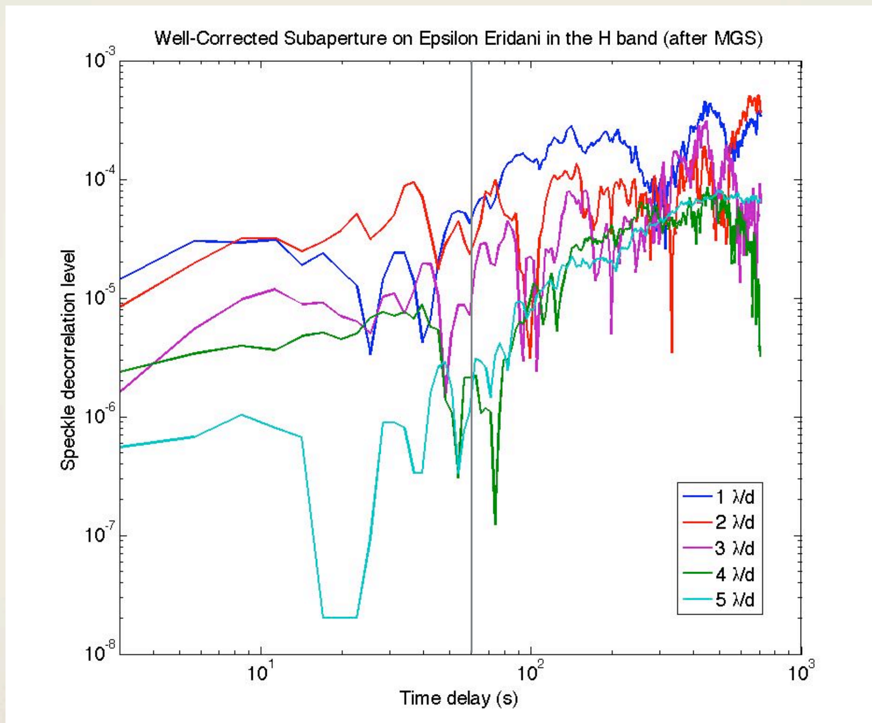
* Observing strategy oriented towards speckle calibration => RDI

The good ol' RDI with GOCI



Observing strategy based on speckle decorrelation

1 ppm / min



Extreme AO on sky data !

Strategy - RDI

What is the best on can do without a CAL system and (quasi)simultaneous differential imaging?

MGS 1-3 iter.	Target	Ref	Target	Ref	...
10-30 min	~ 10 min	~ 10 min	~ 10 min	~ 10 min	

<30 sec
Minimize overheads

Reference chosen with:
- same Vmag, K/H mag as the target.
- same dec, ΔRA ~ 10 min

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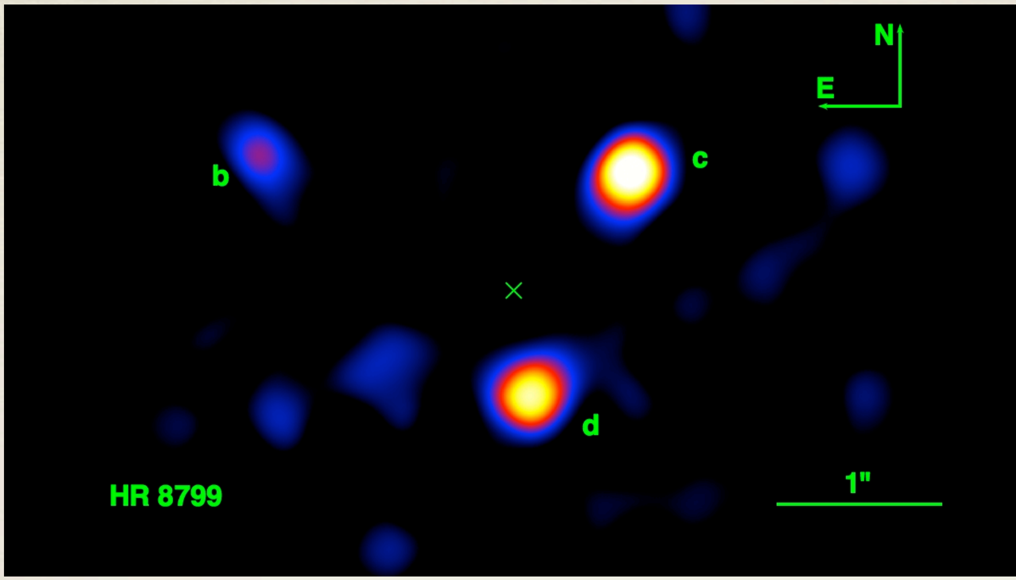
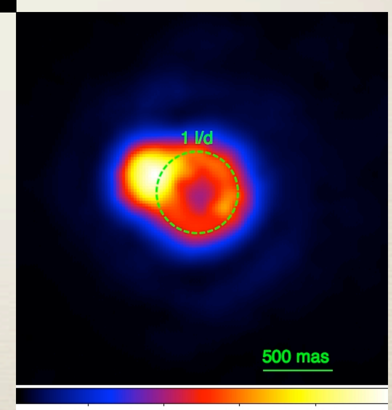
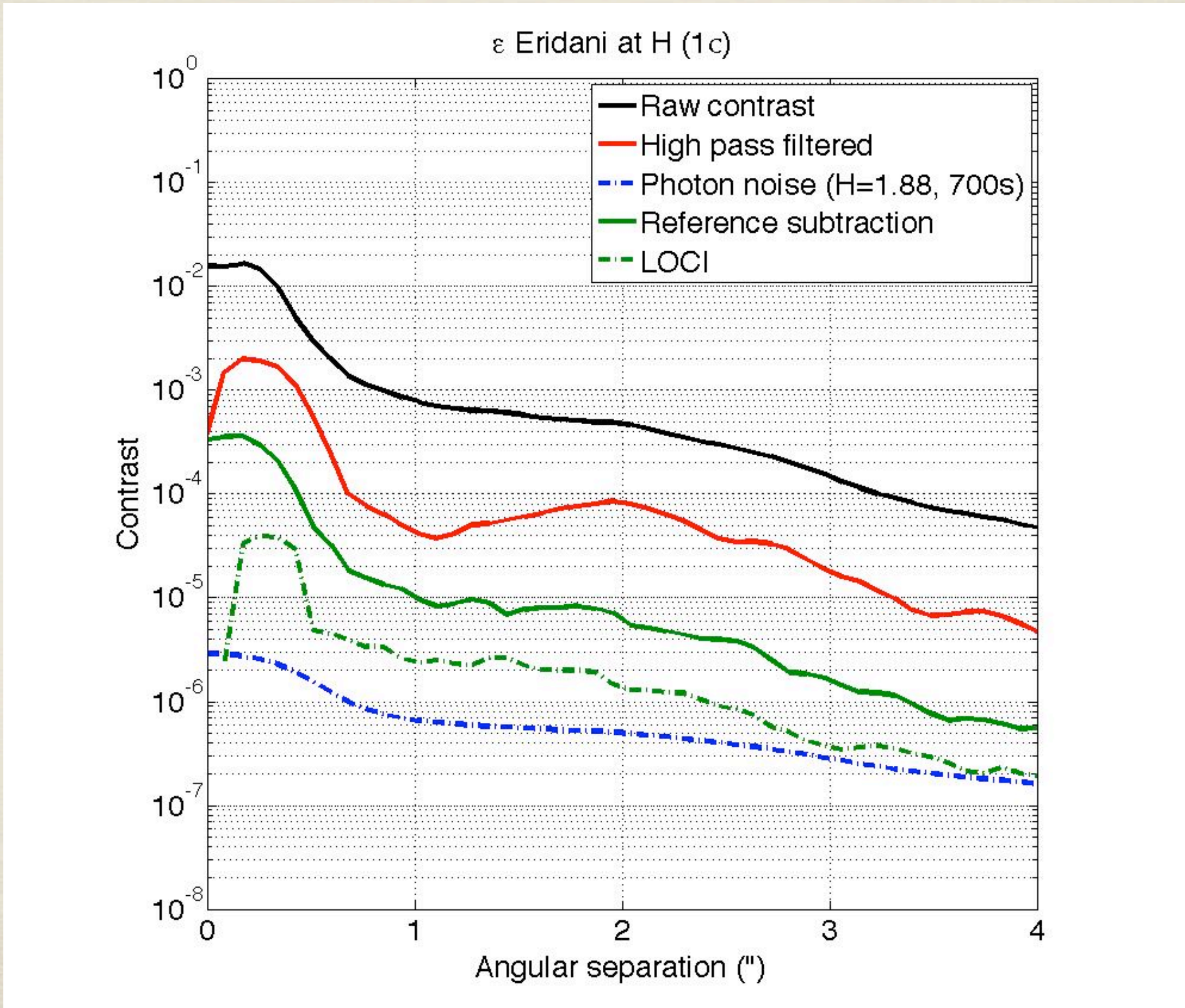
* Smart data reduction method => GOCI & LOCI

A few results





Contrast analysis



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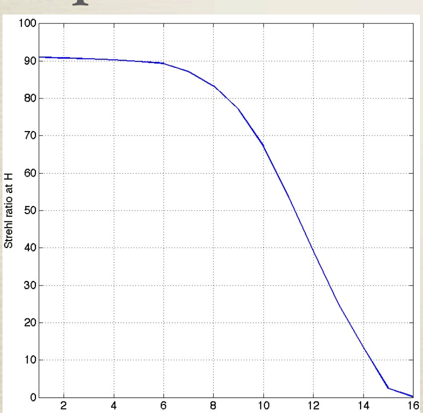
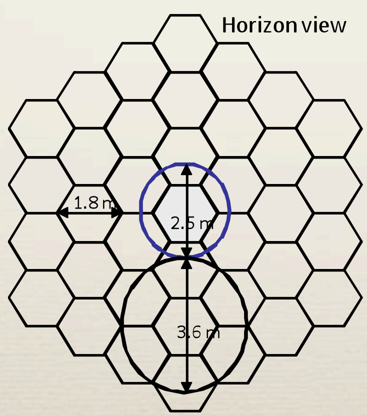
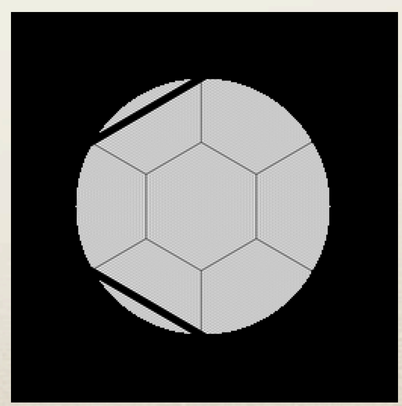
Future

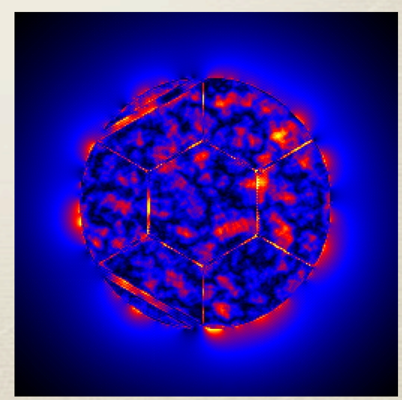
- P3K - P1640 - Pharo/Vortex: finest ExAO system in the world (64x64 DM for a 5 m aperture), only one in the Northern hemisphere, best correction and largest outer working angle !

- WCS at Keck (18 x 18 DM on a 3.6-meter off-axis portion of Keck)









Wanna know more about the vortex ? Come see my posters !